Measurement of Non-Linear Internal Waves and their Interaction with Surface Waves using Coherent Real Aperture Radars

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LONG-TERM GOALS

The long-term goal of this project is to understand microwave surface signatures of internal waves in the ocean so that they can be remotely detected and predicted better.

SCIENTIFIC OBJECTIVES

The scientific objectives of this research are 1) to understand the transition from the linear perturbations of surface waves by internal waves studied in the past to the non-linear perturbations embodied by wave breaking, 2) to determine the conditions that make microwave surface signatures of internal waves visible, and 3) to understand better the generation, propagation, and dissipation of internal waves on the ocean

APPROACH

Our approach is to mount Doppler radars on airplanes and ships to image surface effects of internal waves. We do this while other investigators collect surface and subsurface data to determine environmental conditions and the characteristics of the internal waves. By analyzing these data sets together, we determine how properties of internal waves, wind, and surface waves affect the observed microwave signatures. In FY05, we mounted a Doppler radar on the R/V Revelle and collected data in the South China Sea. In FY06 we mounted Doppler radars on the R/V Endeavor and on a Cessna Skymaster airplane and made measurements off the New Jersey coast. In FY07, we mounted a Doppler radar on the Taiwanese ship OR1 and made measurements in the South China Sea.

WORK COMPLETED

In March, 2005, we installed our pulsed Doppler radar, RiverRad, on the R/V Revelle with its parabolic antennas pointed toward the ship's bow. Measurements were made in the South China Sea as part of SCS05. In August, 2006, we mounted RiverRad on the R/V Endeavor with parabolic antennas that scanned through about 78 degrees. Measurements were made off the New Jersey coast as part of SW06. In both cases, one antenna was vertically polarized and the other was horizontally polarized. These two installations are pictured in Figure 1.

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Figure 1. RiverRad mounted on the R/V Revelle in 2005 (left) and on the R/V Endeavor in 2006 (right). The parabolic antennas were fixed in 2005 and scanned in 2006.

Also in SW06, we mounted our airborne Doppler radar, CORAR, on a Cessna Skymaster leased from Ambroult Aviation of Chatham, MA. Two antennas were mounted under the fuselage, one vertically polarized, the other horizontally polarized. We flew patterns over the ships operating near the internal waves generated at the shelf break on 15 occasions on 11 different days. The installation is shown in Figure 2.

Figure 2. CORAR mounted on the Cessna Skymaster in 2006 during SW06. Left - Electronics rack in the plane. Right – Antennas mounted underneath the plane.

Finally, in April, 2007, we mounted our RiverRad system on the Taiwanese ship OR1 and left it on for two complete cruises totaling three weeks. On the first, two-week cruise the ship operated around Dongsha Island and on the continental shelf. On the second, shorter cruise, the ship operated just west of Luzon Straits and out into the deep basin of the South China Sea. The PI, William Plant, accompanied the radar on this cruise. Figure 3 shows RiverRad mounted on the OR1.

Figure 3. RiverRad mounted on the Taiwanese ship OR1. The parabolic antennas were fixed looking forward during the cruises.

RESULTS

Our measurements showed some very interesting characteristics that we are still studying. One feature of these signatures is that internal waves always modulate backscatter cross sections at HH polarization more than at VV polarization. This was a very clear message from our measurements at many incidence angles as illustrated in Figures 1, 2, and 3.

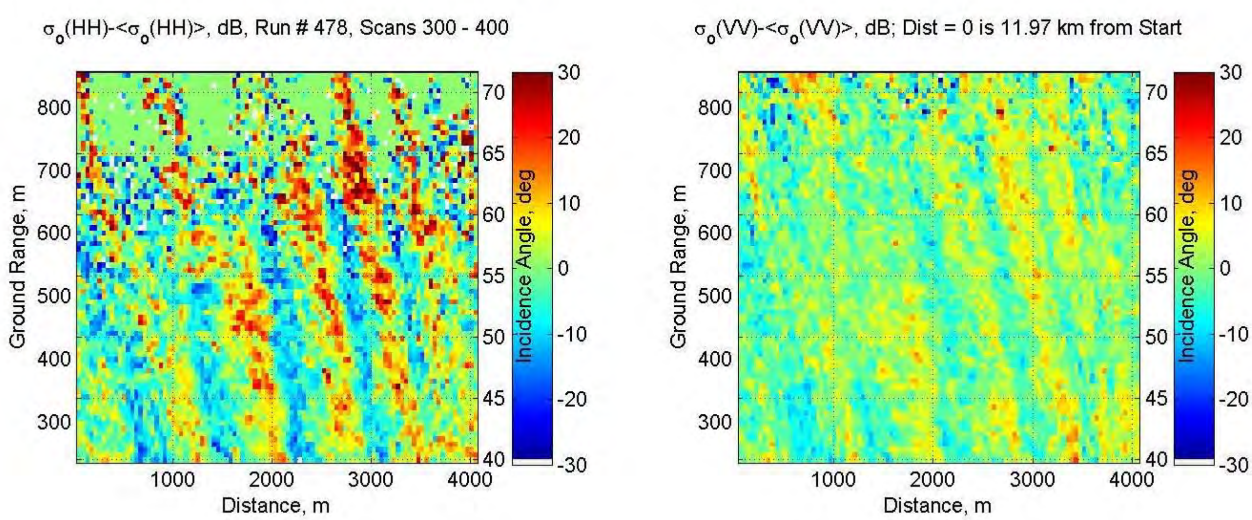

Figure 1. Images of internal waves on the New Jersey shelf obtained with the airborne CORAR. Left: HH polarization, Right: VV polarization.

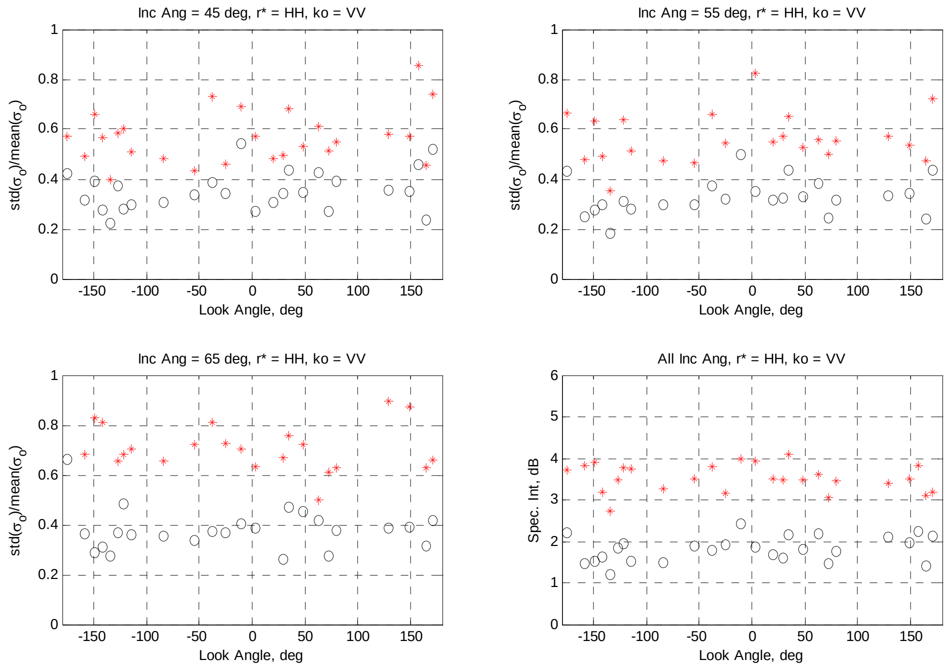

Figure 2. Measures of the visibility of internal waves on the New Jersey shelf by airborne CORAR plotted against antenna look direction. Red asterisks are HH polarization, black circles are VV.

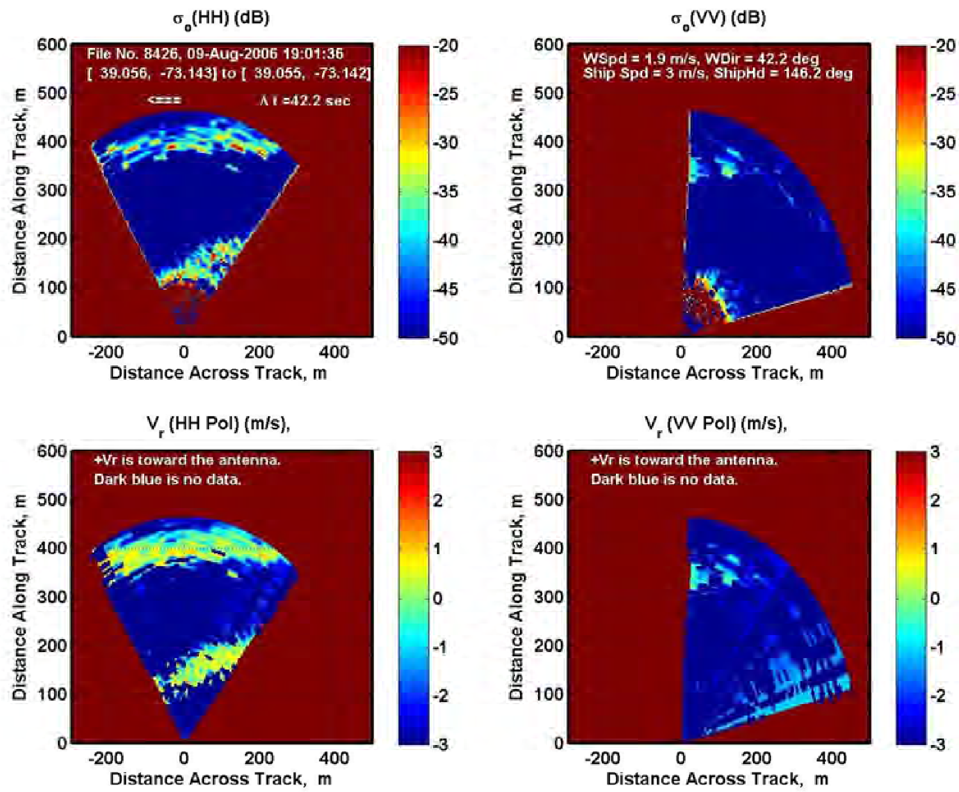

Figure 3. Images of internal waves on the New Jersey shelf obtained with the shipboard RiverRad. Incidence angles were near 88^o. Left column: HH polarization, right column: VV; Top row: cross sections, bottom row: velocities.

In all these figures, the internal waves are more visible for HH polarization than for VV. Interestingly, Figure 3 shows that the internal waves are more visible at HH than VV in the velocity images as well as in the cross section images. Note that the greater visibility at HH than VV polarization is consistent across the range of incidence angles from 45^o to 88^o.

A feature of our data that is not consistent across this range of incidence angles is the dependence of the visibility of internal waves on the direction from which they are viewed. Figure 2 shows that no dependence on azimuth angle exists for incidence angles between 45^o and 65^o. Yet Figure 4 is a shipboard image of the same internal wave seen in Figure 3 but observed from the opposite direction. Clearly the visibility of the internal wave is much less here. The two images were obtained 30 minutes apart.

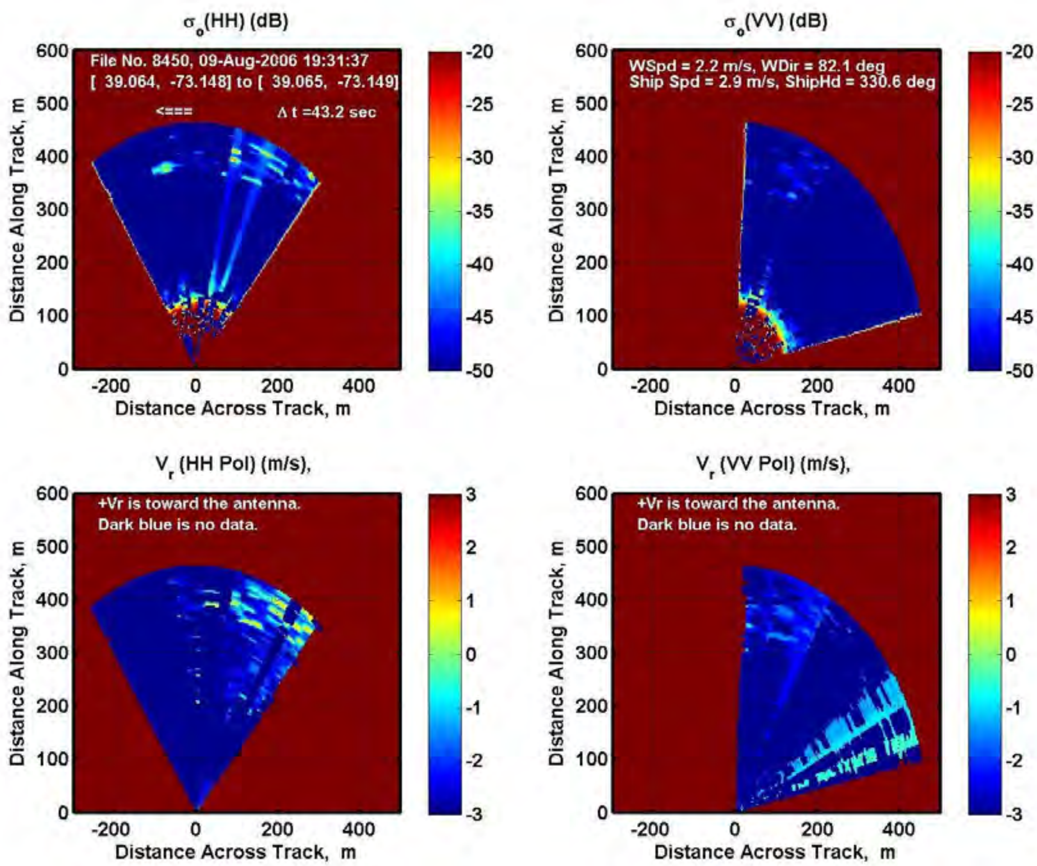

Figure 4. The same internal wave as seen in Figure 3 but viewed from the opposite direction 30 minutes later.

Figure 5 shows that images obtained on ships do not always show internal waves better when looking into their propagation direction. This figure shows the normalized radar cross section observed on several crossings of a train of internal waves traveling west in the deep basin of the South China Sea. Concentrating particularly on wave #2, we see that the cross section looking in the wave propagation direction (second crossing) is larger than that obtained looking into the internal wave propagation direction (first and third crossings). This is very different than Figures 3 and 4.

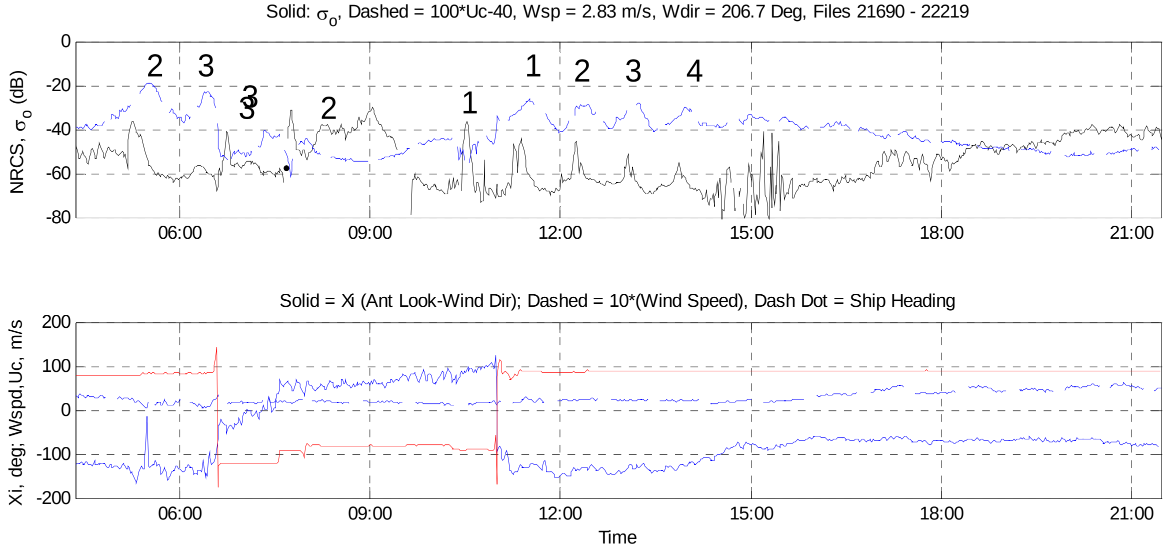

Figure 5. Top: Subsurface velocities in the direction of the ship heading (blue, times 10, minus 40) and normalized radar cross section (black). Bottom: Antenna look direction minus wind direction (solid blue), wind speed times 10 (dashed blue), and ship heading (red).

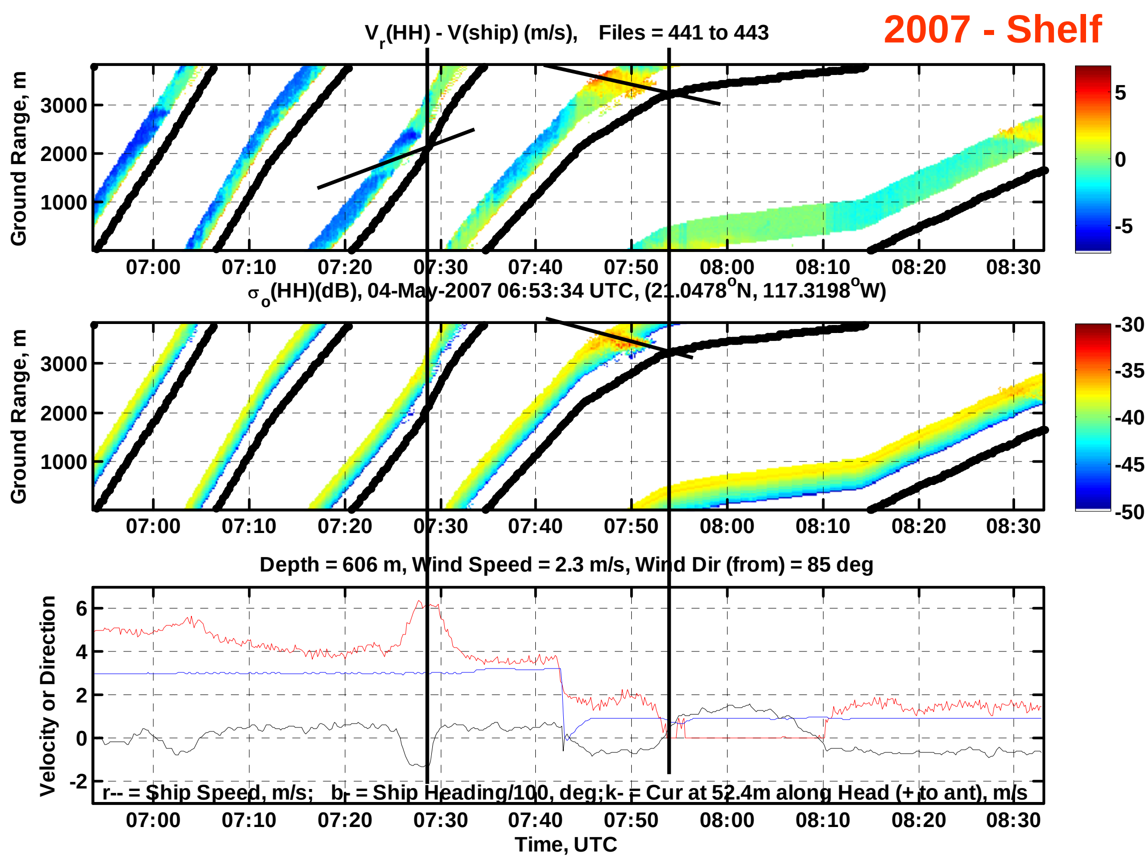

Figure 6. Data taken by RiverRad on the shelf in the South China Sea along with data collected by other instruments on the ship. Top: space/time plot of scatterer velocities observed by RiverRad; Middle: space/time plot of normalized radar cross sections from RiverRad; Bottom: component of subsurface velocity along the ship heading (black), the ship heading (blue), and the ship speed (red).

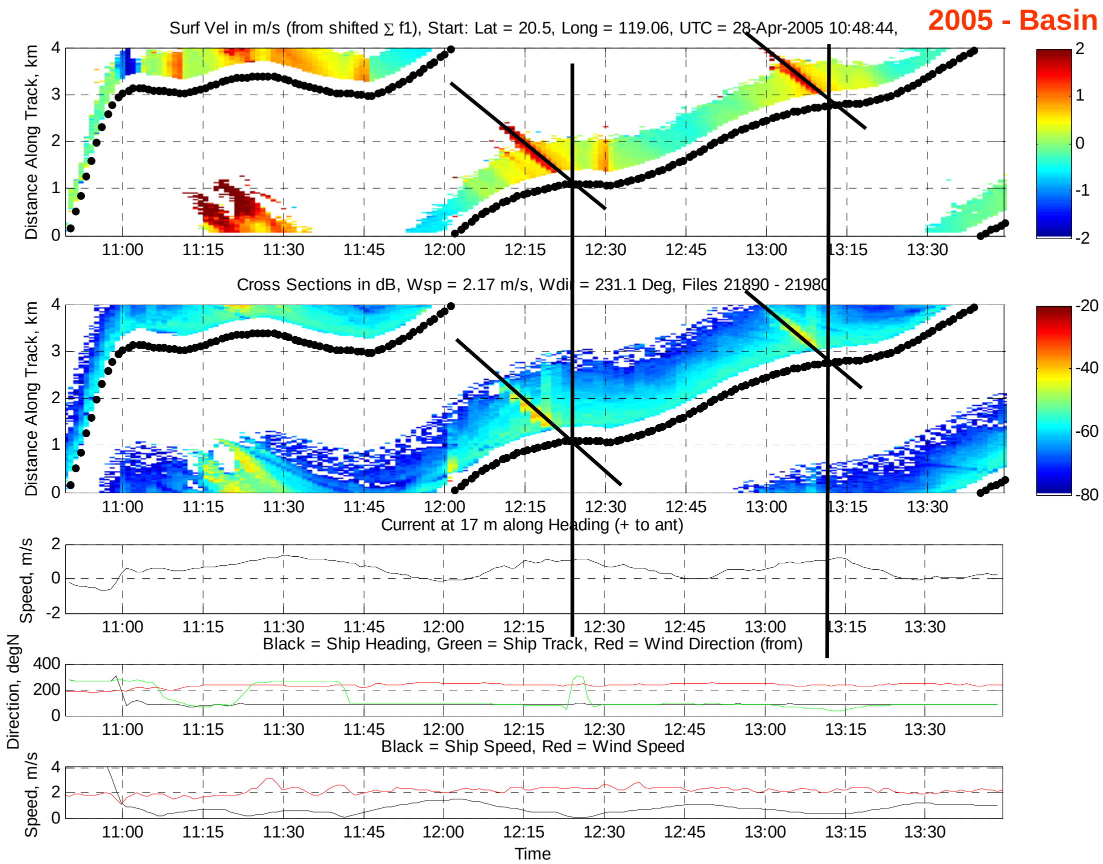

Figure 7. Same as Figure 6 except that data were taken in the deep basin of the South China Sea. Here the middle plot shows the subsurface velocity component in the direction of the ship heading (positive is toward the ship's bow).

Finally, the location of the maximum cross section is conventionally thought to appear on the leading face of the internal wave, where the rate of strain attains its largest negative value. However, our measurements suggest that this depends on the type of internal wave. Figures 6 and 7 show space/time plots of the return to RiverRad. The black curve in the figures is the ship's path. The lower panels show the component of subsurface velocity along the ship heading, the ship heading, and speed. They also give wind speed and direction.

We may track the progress of any internal wave in the figures as shown by the sloping black lines in the figures. The points where these lines cross the ship's path are the locations of the internal wave signatures at the time that the velocity measurements in the bottom panel were made. The vertical black lines trace these points down to the subsurface velocity components in the direction of ship heading. Clearly on the shelf, the maximum cross section occurs on the front face of the internal wave as conventional wisdom dictates. However, in the deep basin, the maximum cross section occurs at the maximum of the subsurface velocity. This is unexpected and unexplained. Furthermore, the maximum of the scatterer velocity appears to follow that of the cross section, again unexplained.

IMPACT/APPLICATION

These measurements and associated future modeling will help establish the relationship between remotely observed microwave signatures of internal waves on the sea surface and the properties of the internal waves. This will aid in the prediction of internal wave location and amplitude for use in submarine navigation and acoustic propagation calculations in the internal wave field.

TRANSITIONS

The results of this project have not yet been transitioned for operational use.

RELATED PROJECTS

This project is part of the NLIWI experiment and is strongly related to the WISE/VANS experiment and to the Surface Wave 06 acoustic experiment.